# ABSTRACT

## ENHANCED ENERGETIC MATERIAL FUNCTIONAL TEST SYSTEM



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An explosive containment chamber and instrumentation system has been developed by Applied Research Associates, Inc. personnel (while employed for the Denver Research Institute [DRI]) and DRI personnel for the Crane Division of the Naval Surface Warfare Center (NSWC). This development, the Enhanced Energetic Materials Functional Test System (EEMFTS), is for the testing and quality evaluations of energetic materials. The EEMFTS consists of an explosive containment chamber, pollution abatement unit, timing/sequencing, controller, safety/interlock circuitry, and a comprehensive data acquisition and analysis system. The EEMFTS provides the Navy with an all-weather test capability to function fuzes, boosters, bursters, small-scale cook-off, and card-gap tests. Test performance is measured and documented with laboratory accuracy and resolution.

Specifically, the EEMFTS containment chamber was designed for the testing of up to 1.1 pounds (500 grams) of high explosive metal cased (fragmenting) devices on an unlimited life cycle basis. Computer model simulations were performed on the containment chamber design to substantiate loading function designs. The chamber is lined with sacrificial metal plates to protect the outer structure from fragmentation damage. Camera view ports allows photographic documentation of the set-up and detonation phase of the tests. An automated air control system enables the system to confine combustion products during the detonation phase and directs the post-event effluence to the pollution abatement unit, which enables the “scrubbed” gases to be directed out of the building into the atmosphere.

A control console enacts all support roles required for conducting the test event, including detonator initiation, transducer signal conditioning, signal recording, chamber control, event sequencing, safety monitoring, and data reduction. The instrumentation suite supporting the EEMFTS consists of high performance pressure, temperature, strain, and fiber optic velocity of detonation (VOD) sensors (with a digitizing rate to one nanosecond), signal conditioning, analog to digital conversation and memory storage capability. Facility and personnel safety is ensured by manual and automated safety and interlock circuitry providing assurance of chamber and building interlock pre-event integrity. Data analysis procedures are performed via custom, menu based, macro implemented routines. Report ready hard-copy results (in engineering units) are available within minutes of test completion.

The EEMFTS provides a cost effective approach in performing energetic materials testing. This is accomplished by the effective application of integrated mechanical and electronic technologies used for the efficient testing and quality evaluation of fuzes, boosters, bursters, small-scale cook-off, and card-gap tests for NSWC.

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**PRESENTATION**

# ENHANCED ENERGETIC MATERIAL FUNCTIONAL TEST SYSTEM

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# INTRODUCTION

An Enhanced Energetic Material Functional Test System (EEMFTS) has been developed by Applied Research Associates, Inc. (ARA) personnel (while employed at the Denver Research Institute [DRI]) and DRI personnel, for the Naval Surface Warfare Center (NSWC), Crane Division. The EEMFTS was developed in response to new test procedures used for the testing and quality evaluation of energetic materials and the need to conduct small-scale cook-off and card-gap testing in a controlled environment. These additional requirements dictated the need to modify the Energetic Material Functioning Test System (EMFTS), which NSWC has been operating since 1991, to conduct functional evaluations of various explosive components and materials. Key components of the EMFTS instrumentation suite were used as the basic measurement system for the EEMFTS. In addition, enhanced instrumentation systems were included to allow more accurate collection of data. The EEMFTS consists of an explosive containment chamber, pollution abatement unit, timing/sequencing controller, safety/interlock circuitry, and a comprehensive data acquisition and analysis system. The combined capabilities of this system provides all weather test capability to function and evaluate the performance of fuzes, boosters, bursters, small-scale cook-off, and card-gap tests. The pollution abatement system alleviates environmental concerns by "scrubbing" the combustion products prior to release to the atmosphere.

The EEMFTS was designed and developed to operate autonomously in characterizing energetic material performance up to 1.1 pounds net explosive weight on an unlimited life cycle basis. The system is located indoors where test schedules and productivity are unaffected by meteorological conditions and long trips to normal energetic material test ranges.

# SYSTEM OBJECTIVES

The objective of the system design was to provide a test unit which would provide laboratory quality measurements of energetic materials subjected to quality evaluations. These materials include fuzes, boosters, bursters, small-scale cook-off, and card-gap tests. Key objectives of the system design included indoor operation and incorporation of a pollution abatement system which allows operations in any weather conditions without concern for environmental effects. Specific system objectives are listed below:

## Energetic Material Containment Chamber

- Fully contain, cased (fragmenting) devices with net explosive weights of up to 1.1 pounds, with an unlimited life cycle.
- Provide sacrificial fragmentation plates to protect chamber walls from the detonation of cased devices.
- Provide view ports for photographic/video monitoring-one for light & the other for the camera.
- Provide two doors into the chamber-one for heavy equipment, etc., and the other for personnel.
- Provide air ducts, valves, and controllers for sequencing the pre- and post-event environments.

- Provide positive interlock and safety control for building and personnel.
- Measure explosive detonation parameters of: velocity of detonation, fragment velocity, chamber pressure and chamber temperature.
- Measure chamber stress/strain values for qualification and safety monitoring of every test.
- Provide pollution abatement system for filtering the combustion by-products before venting to the atmosphere.
- Provide cabling/trays and interfacing to the instrumentation system.

**Instrumentation and Control System**

- Integrate EMFTS instrumentation into the EEMFTS console.
  • Including timing/sequencing, signal conditioning, data acquisition and analysis.
- Provide automated interlock control and safety switches.
- Provide ultra-high speed fiber optic diagnostic system.
- Provide video monitors and cameras for documenting preparations and event.
- Provide power source and controller for slow cook-off tests.
- Provide test diagnostic system for operational requirements.

## DESIGN APPROACH

System design was driven by two fundamental requirements. One of the requirements was that the explosive containment chamber would have to perform on an unlimited life cycle basis with 1.1 pounds of fragmenting high explosives and the other requirement was that the EMFTS instrumentation be merged into the EEMFTS control console with improved diagnostic instrumentation added to enhance energetic material measurement performance. The following discussion details the design approach for the containment chamber (with pollution abatement), and the instrumentation/control console used to support the chamber testing.

**Explosive Containment Chamber**

A chamber was designed that is approximately 7.0 feet in diameter and 12.5 feet long. This size provides the volume needed for experimental purposes and is small enough to physically fit into the NSWC Crane facility. Blast and fragment loading criteria were determined by the test types and protocols. The high order detonation of the test items produces three specific load components. The loads are: the fragment impact against the chamber's interior surfaces, the blast wave impact against all interior surfaces, and the quasi-static pressure ultimately acting against the outer shell of the chamber. The maximum net explosive weight for any of the tests is 1.1 pounds for the card-gap evaluations. Static overpressure and temperature estimates from the confined blasts were determined from the NASA-LEWIS Thermodynamics Code. Maximum fragment velocity from the test items of booster Quality Evaluation, scaled cook-off, and card-gap were derived from Gurney calculations.

A three dimensional Lagrangian finite element (FE) modeling code was used in the design and analysis of the chamber design. The DYTRAN V2 analysis code employed was developed by the Mac-Neal Schwendler Corporation (MSC). The MSC/DYTRAN is a 3-dimensional code for

analyzing the dynamic, non-linear behavior of solid components, structures, and fluids. It uses explicit time integration and incorporates features to simulate a wide range of material and geometric non-linearity. In order to simplify the loading calculations, the chamber was divided into four loading zones. Numerous iterations of the calculations were performed with design refinement incorporated and re-calculated until the design point was reached in which the maximum transient strain state was well below the fatigue point of the chamber components. The final design was based upon the use of 0.75 inch carbon steel for the outer shell reinforced with rib and flange assemblies supporting the shell and for mounting of the sacrificial plates inside the chamber. The design also incorporates two access doors. The large door, opening the full diameter of the tank, allows pre-positioning of test item hardware and interior chamber maintenance, and a smaller personnel door which provides easy access for normal operational procedures.

Sacrificial plates made of 0.5 inch thick carbon steel were mounted to the interior walls of the chamber which is needed to prevent the test item fragmentation from damaging the outer containment shell. These plates are replaced as needed and provide an unlimited lifetime for the chamber. Two view ports were constructed into the chamber providing lighting and camera coverage to the interior of the chamber. Figure 1 shows the sacrificial plates and the view ports mounted into the containment chamber. The view ports were fitted with inserts holding first surface mirrors to direct the views from the interior of the chamber to the externally mounted light source and camera. The pressure seal from the port ducting to the outside atmosphere is accomplished by the use of Lexan windows. Other ports are provided for the in-chamber instrumentation, firing, control, and power systems. Additional ports were installed to allow inlet air to be ducted into the chamber, sealed during the test scenarios, and then ducted to the pollution abatement system post-event.

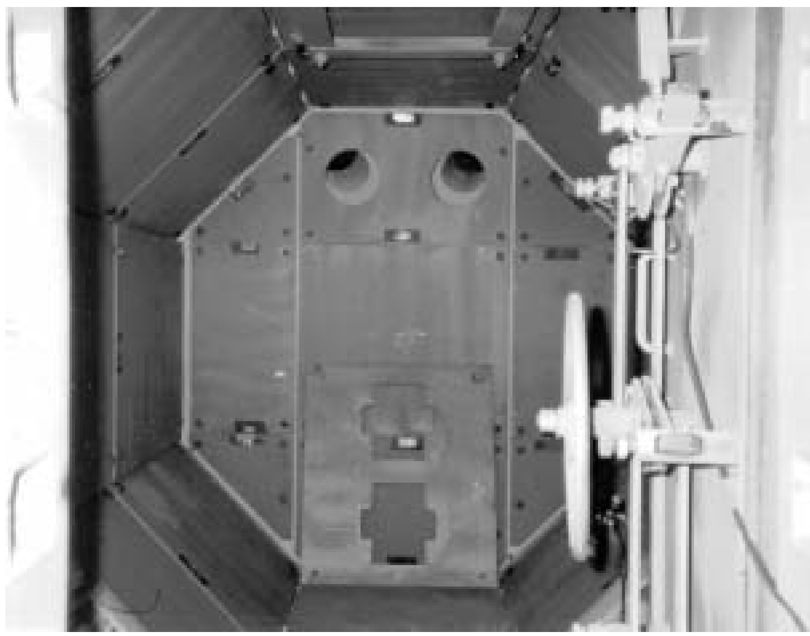

Figure 1. View of chamber interior with sacrificial plates and view ports.

Instrumentation mounted on the chamber includes seven strain gages to monitor structural characteristics during testing, and interlocks on both doors for safety and control purposes. Control switches were also installed on the air ducting valves for automatic control sequencing.

The chamber was interfaced to a pollution abatement system as shown in Figure 2. The filtration part of this system was based on calculation for the airflow into and our of the chamber.  A weekly volume of 1.3 gallons of bulk powder would be generated assuming 10 shots per day/ 5 days per week with each shot consisting of 1.0 pounds of TNT, each with a particulate loading of 100 grams of carbon products.  This is a very conservative approach..  Based on these calculations, an Aercology Model DMH-1500 dust collection system was selected.  This system incorporates three filters to cleanse the air.  A large area bag filter is used to filter the larger particulate material, a carbon filter removes the organic compounds, and a HEPA filter is used to remove the microscopic particles.  An automatic shaker system cleans the large area bag filter and the removed material is loaded into a 55-gallon drum located under the unit.


Figure 2.  Pollution abatement system.

**Instrumentation and Control Console**

The majority of instrumentation related equipment used to document the containment chamber tests was taken from the EMFTS (originally a two rack, semi-portable unit), to reduce system costs.  The main equipment items used from the EMFTS for the EEMFTS are listed below:

- Test controller/sequencer which produces 16 independent output control signals to function test equipment related to the containment chamber test scenario from selected start (pre-shot) and stop (post-shot) times.

- Two firing systems comprised of a Reynolds high voltage exploding bridge wire detonator firing unit and a custom designed low voltage capacitive discharge firing unit.

- Signal conditioning consisting of six channels of piezoelectric and six channels of wheatstone bridge. This conditioning allows the use of most of the commonly available blast transducers.

- Twelve channels of fiber optic light-to-voltage converters (rise time of 350 nanoseconds) to monitor fuze train functioning time and explosive velocity of detonation.

- Twenty channels of 12-bit, analog to digital converters, recording at a maximum rate of 5 megasamples per second with 2.56 megabytes of on-board memory.

- Computer system with 200 megabyte hard drive, 3.5”/5.25” floppy drives and a 44 megabyte Bernoulli drive.

- Power conditioning and uninterruptible power systems to provide stable system power.

In addition to the EMFTS instrumentation system detailed above, several important improvements to the EEMFTS were implemented to enhance diagnostic ability and to provide other test item capability. It was also necessary to provide the control and interface/interlock hardware for remotely functioning the containment chamber system in a safe manner. Details of these system additions are listed below:

- Six channels of ultra-high speed fiber optics. This system is used for velocity-of-detonation (VOD) information with each channel sampling at a maximum rate of 1.0 nanosecond/sample. Due to the extreme accuracy needed for these measurements, glass fiber was interfaced from the containment chamber to the instrumentation console. The light signal is then converted to electrical inputs for the digitizers by closely coupled ultra-high speed amplifier systems.

- A DC power source was incorporated into the EEMFTS to provide excitation for the cook-off tests. This supply is controlled by a precision digital temperature controller with visual readout and confirmation.

- Two video cameras and two monitors were interfaced to the EEMFTS. One camera shows the interior view of the chamber and the other camera shows an overview of the containment chamber area, providing additional safety and documentation information.

- A Tektronix TM-500 test system was installed into the instrumentation console to assist in test set-up and in performing troubleshooting procedures.

- An interlock and control panel was designed into the instrumentation console to provide the monitoring and safety interrupts generated from the facility doors and the chamber interlock sensors. A schematic of the chamber system is displayed at the control console with LED lights showing the status of the facility and indicating sequenced operation. This system monitors all entrances into the room that houses the containment chamber. If any of the doors are opened, the firing system would be automatically disabled, and the status lights would indicate the location of the breached entry way. The air ventilation sequence is initiated by the operator and the controller assures air flow and valve positions are sufficient to purge the chamber into the pollution abatement system, post-event. If air flow is insufficient, or a valve malfunctions, an alarm sounds alerting the operator to the deficiency.

## SYSTEM INTEGRATION

The components used for the EEMFTS were integrated into a system providing semi-automated control, acquisition, and analysis of energetic material testing and evaluation. Figure 3 depicts the block diagram of the system. It shows the instrumentation console, located in the control

room, with cable/cable tray interfacing to the containment chamber.  The instrumentation patching, temperature converters, firing systems (x-units), power feeds, and control relays are mounted in four, floor mounted housings, in close proximity to the containment chamber.

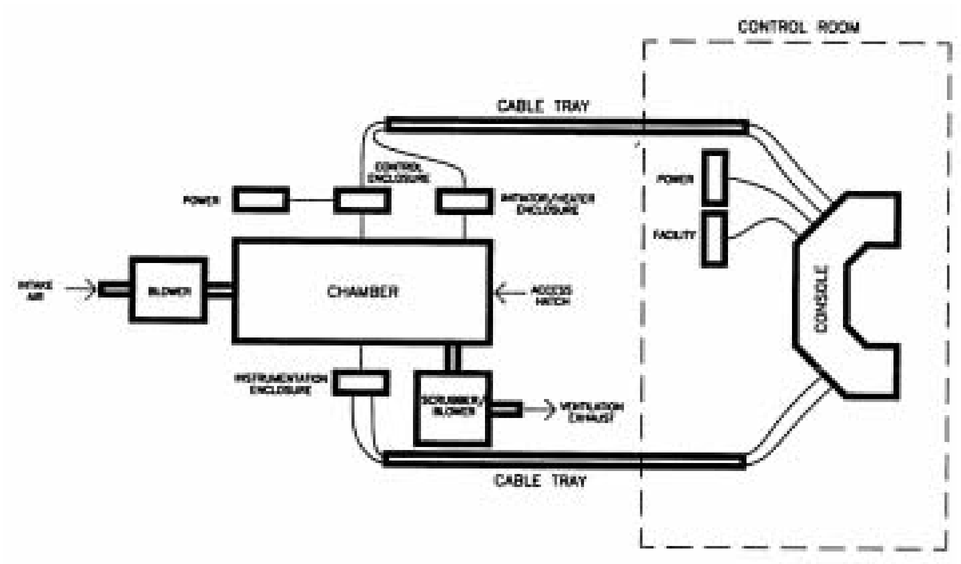


Figure 3.  Block diagram of system.

The instrumentation console, shown in Figure 4, is interfaced to the containment chamber (Figure 5) by cabling positioned in the cable trays.  The Aercology unit was plumbed into the chamber via ductwork and valves.

Figure 4.  Instrumentation console.

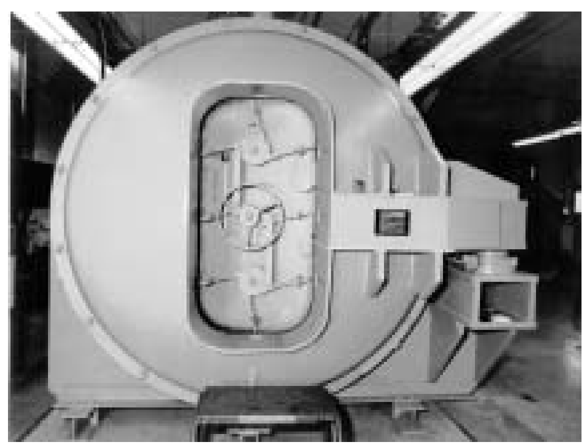

Figure 5.  Explosive containment chamber.

## SYSTEM QUALIFICATION

Before the system was shipped to NSWC Crane for operations, the containment chamber and instrumentation console was setup at a local test facility for system qualification. The qualification testing consisted of two components; one, verify chamber pressure, temperature, and stress/strain values are within design limits when subjected to 1.1 pounds of high explosive detonation, and two, demonstrate sacrificial fragment plate performance by testing performed external to the chamber.

Demonstration of fragment plate performance was accomplished by separate detonations of a slow cook-off bomb and a card-gap casing. The distance from the tested devices to the fragment plate was the same as if detonated in the chamber. Results of these detonations showed that it was possible, in extreme cases, to penetrate the 0.5 inch fragment barricade. Because of this information, another layer of hardened steel was installed for additional chamber shell protection. Figure 6 depicts the test set-up for the cook-off test. Notice the fragment plate in the background, replicating the worst case wall barricade, and the overhead fragment plates replicating the ceiling of the chamber which is protected by multiple 0.5 inch sacrificial plates.

Figure 6. Cook-off fragmentation test.

Qualification of the containment chamber for quasi-static pressure, temperature, and stress was accomplished by the detonation of five, bare C-4 charges. The weights of the five charges were 0.25, 0.5, 0.75, 1.0 and 1.44 pounds of C-4. For each test, the quasi-static internal pressure, internal temperature, chamber wall stress, and event total light was measured and evaluated prior to the next test to provide assurance that design limits were not being approached. Critical chamber data resides in the hoop stress. With the chamber constructed of ordinary structural steel, it is important to keep hoop stress below 25 ksi, equating to approximately 833 micro inch/inch strain reading, which would essentially imply infinite cyclic tolerance. All test data demonstrated that the design limits were not being exceeded, even for the final proof overload of 1.44 pounds of C-4. The stress value for the proof load of 1.44 pounds high explosive was 600 micro inch/inch, therefore, the design load of 1.1 pounds would ensure an unlimited life cycle of the chamber. Figures 7 and 8 show respective quasi-static pressure and temperature readouts of the 1.44 pound detonation. Figure 9 shows worst case hoop stress.

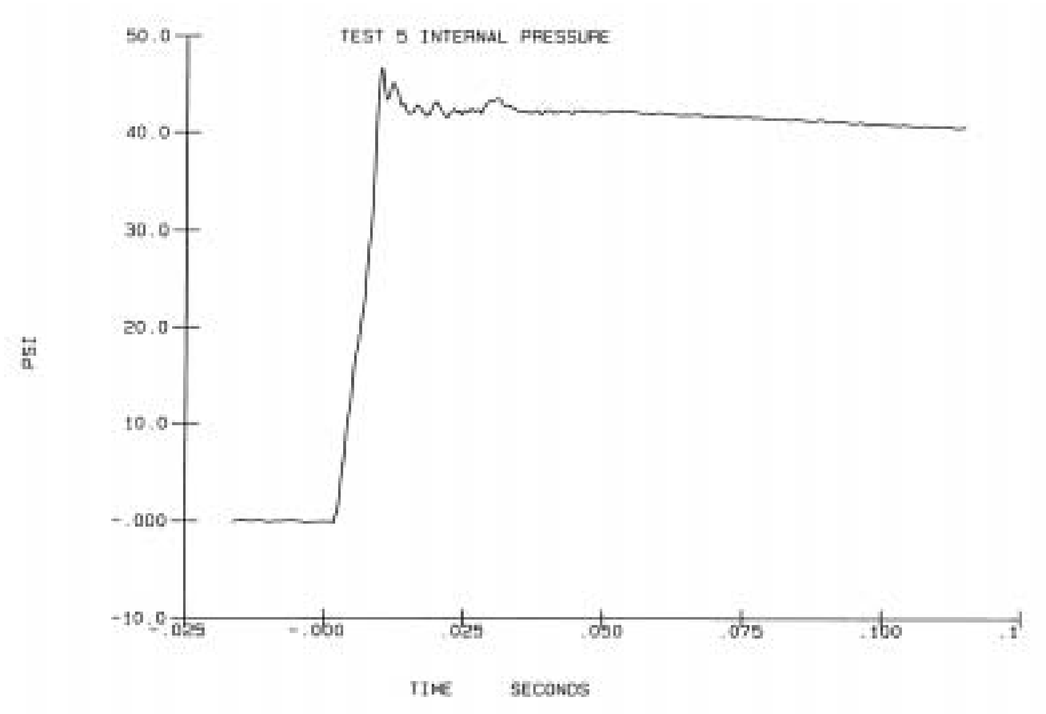


Figure 7. Quasi-static pressure for 1.44 lb. detonation.

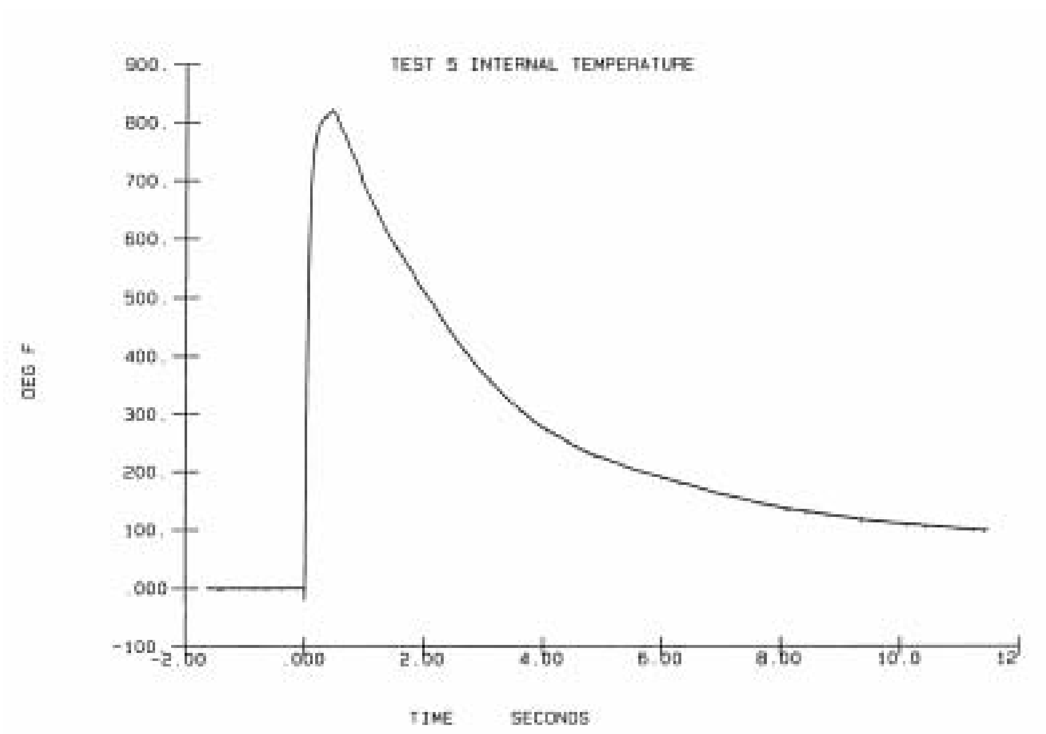


Figure 8. Temperature profile of 1.44 lb. detonation.

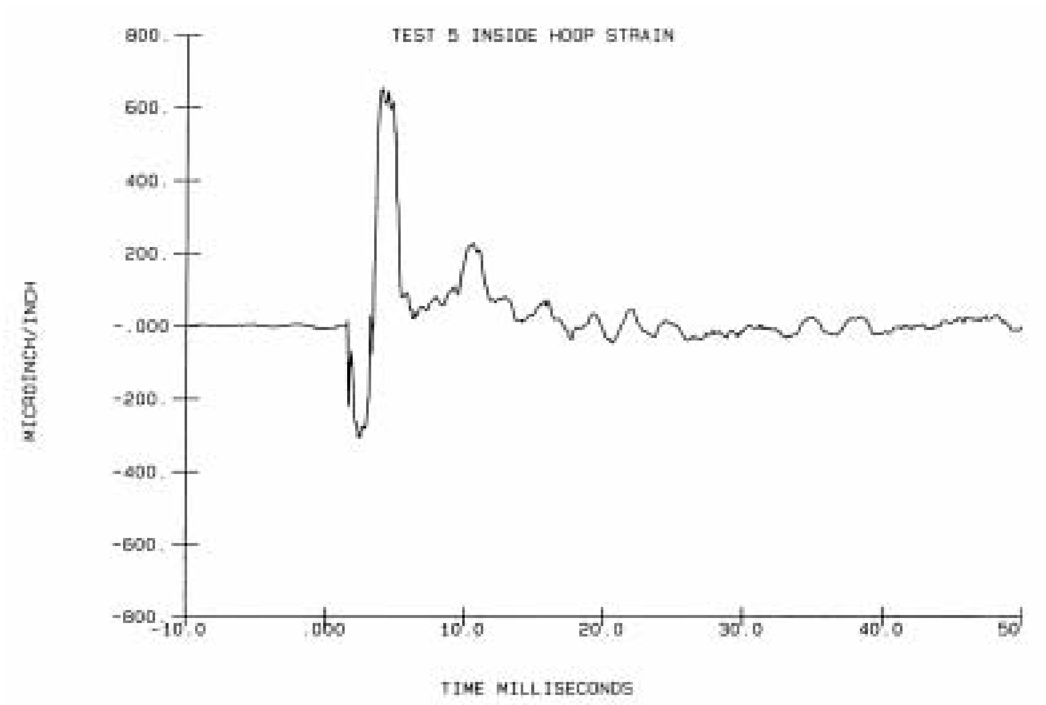


Figure 9. Inside hoop strain for 1.44 lb. detonation.

Following qualification testing, the chamber was shipped to NSWC Crane. The system was integrated into the facility site and full system sequences were performed. Detonations of select energetic materials demonstrated system performance. The EEMFTS is currently operational at the NSWC Crane facility.

## SUMMARY

The EEMFTS is a modern energetic materials test system, complete with high performance instrumentation diagnostics to characterize the performance of fuzes, boosters, bursters, small-scale cook-off, and card-gap tests. The indoor location of the EEMFTS provides the Navy with an all-weather test and evaluation facility providing near laboratory conditions, performance and execution. These attributes contribute to enhanced quality evaluation procedures with reduced operational support requirements, resulting in a cost effective approach for performing energetic material testing.

In addition to the added value inherent with the quality evaluation of munitions, the EEMFTS (because of its comprehensive, high performance instrumentation suite and versatility/flexibility of operation) is ideally suited to support a wide range of energetic material testing and evaluations. The traditional measurements of pressure, temperature, VOD, and fragmentation velocity are available and easily configured to accommodate a wide range of experimental requirements within the containment chamber's net-explosive-weight limits.